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Should we consider climate change for Brazilian social housing? Assessment of energy efficiency adaptation measures

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ABSTRACT

Social housing sector is very important in Brazil, due to the necessity of expansion and investments being placed through a substantial government program. Residential buildings are expected to last at least 50 years according to Brazilian standards. Many residential projects in the sector already perform medium or poorly in terms of energy efficiency and thermal comfort today, and their designs are not analysed considering climate change. Therefore, the aim of this paper is to investigate the result of analysing the thermal and energy performance of social housing projects considering climate change, and to assess the impact on the operational phase of introducing energy efficiency measures in the sector, and exploring methods of adaptation to climate change. A representative project of the lower income sector housing was used as case study with the evaluation of measures through thermal and energy simulation with current and future weather files for the cities of São Paulo and Salvador. Results were compared using predicted energy consumption and cooling and heating degree-hours as indicators. The results highlighted some differences related to the climate scenarios and indicator analysed, and showed that the incorporation of energy efficiency measures in current social housing projects is of fundamental importance to minimize the effects of climate change in the coming decades.

1. Introduction

The construction industry is associated with a high environmental impact due to its use of natural resources coupled with rising demand in line with rapid population growth. A major impact is the energy consumption and associated emissions of greenhouse gases that influence climate change through global warming [1]. Due to the long life in use of buildings, changes in climate can influence energy demand for heating and cooling and consequently the emissions of greenhouse gases from buildings [2]. However, in Brazil most studies of the energy performance of buildings that use thermal and energy simulations to predict building performance only make use of past weather files.

In Brazil, the housing deficit is around 5.8 million, 85.7% is urban and 82.5% affects families with incomes up to a maximum of three times the minimum wage [3]. In 2009 the Brazilian government launched the “My house, My Life” Program, as a strategy to address the deficit [4]. Housing Companies and Public Agents linked to States and Municipalities are the main agencies to deliver housing projects in the lower income sector, and they tend to prioritize projects with lower capital costs [5]. Therefore, more emphasis is commonly placed on initial cost rather than on the operational phase. Researches such as Bodach and Hamhaber [6]; Curcio and Da Silva [7]; Linck et al. [8] and Almeida [9], among others, have shown a poor thermal performance of projects in the social housing sector in Brazil. Also, recent research by Triana, Lamberts and Sassi [10] displayed medium and especially poor thermal and energy performance for projects representative of the lower income sector in relation to the Brazilian Energy Labelling, showing the importance of implementing measures to improve the thermal and energy performance. Buildings with poor thermal performance result in discomfort for users, which could influence the health of occupants, and, as their income increases, the occupants opt for the use of environmental conditioning, increasing the operating cost of the building and CO_2 emissions. An increase of air conditioning country-wide would mean the need for the country to expand its energy infrastructure.

The minimum performance Standard for Residential Buildings in Brazil – NBR 15575 requires social housing to be built for a useful life of at least 50 years. Projects in the sector should be able to

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guarantee this performance, to avoid liabilities that could result in greater cost for the country.

Thermal and energy simulation in buildings can be used to predict future building performance taking into account weather data. For more precise simulation results, it is necessary the use of annual weather files on an hourly basis. The most current weather files used for buildingís simulation in Brazil come from data between 1961–1990, or if more recent, from 1976 to 2005, which does not reflect the trends of climate change.

For impacts analysis, the IPCC establishes future scenarios related to climate change, which allow alternatives for mitigation or adaptation to be evaluated. In 1996 a set of scenarios (SRES) were developed. The SRES scenarios were used in the third and fourth IPCC reports [11]. In the fifth and most recent IPCC report (AR5), published at the end of 2014, it was decided to adopt a new set of scenarios produced by the scientific community [12]. The SRES scenarios covered different alternatives of demographic, economic and technological evolution and were divided into four main evolutionary lines, which create four family scenarios (A1, A2, B1 and B2). In the fifth report (AR5), a limited number of alternatives called RCPs (Representative Concentration Pathways) were estimated, based on concentrations of greenhouse gases, in order to provide representative pathways of climatic futures. RCPs scenarios include 4.5 and 8.5 [12].

Scenarios A2 and A1F1 of IPCC SRES scenarios and RCP 8.5 of the 5th report are considered to be of high emission. The A2 scenario for the SRES scenarios is considered to represent the current trend in the world. Fig. 1 shows the relationship of the trend between SRES and RCPs scenarios.

A method for developing future weather files based on the morphing method by Belcher, Hacker and Powell [14] was proposed by Jentsch, Bahaj and James [15], to adapt EPW (EnergyPlus Weather files) incorporating forecasts of climate change. For this, the Climate Change World Weather File Generator for World-Wide Weather Data (CCWorldWeatherGen) tool was developed, enabling the generation of future weather files for any location in the world. It considers the results from the HadCM3 model using A2 scenario from the III assessment report of IPCC. The problem of the CCWorldWeatherGen is that it does not use the latest report data (AR5) from IPCC, only represents one scenario (A2) and uses global data from IPCC, so no regional data is being used. In Brazil, there is still not much regional data available for future weather. Therefore, and according to Jentsch et al. [16] until more regional data is produced, "morphed" weather files produced with the CCWorldWeatherGen tool can be used for a practical approach to studying the impacts of climate change in buildings.

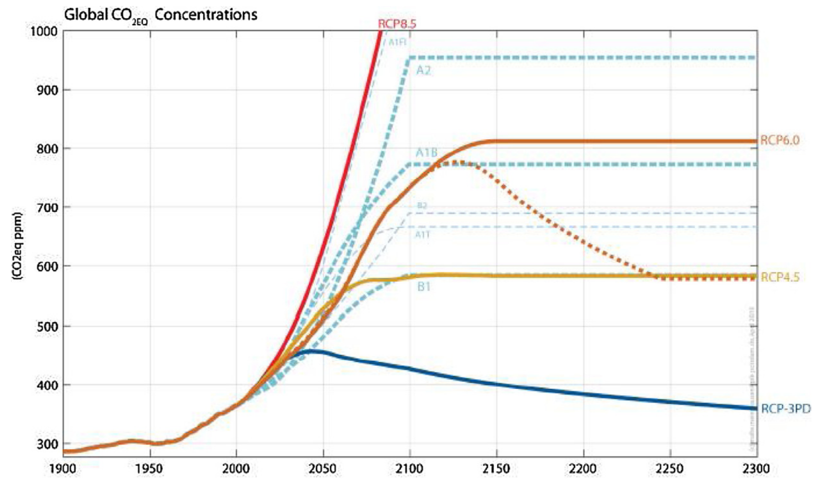
In relation to climate change strategies for buildings there are two different approaches: mitigation and adaptation. Adaptation can be done by enabling the capacity of adaptation through a better energy performance of the building [17]. Some studies evaluating energy efficiency adaptation measures have been undertaken especially in more developed countries where regional climate data is more available. Van Hooff et al. [18] investigates six passive climate change adaptation strategies for three typical residential buildings of two different periods in Netherlands. Results indicate that exterior solar shading and additional natural ventilation were the most effective strategies, and for more insulated buildings, additional measures will be needed. Similarly, Gupta and Gregg [19] studied seven adaptation options in four typical typologies of existing dwellings in England. Shading controlled by the user proved to be the best strategy, however, none could totally eliminate the risk of overheating in homes, considering the year 2080. Ren, Cheng and Wang [17] researched climate change adaptation for Australian residential buildings considering simulation and costs-effectiveness in existing and new buildings in eight bioclimatic zones. Results indicated that cooling and heating end uses were dominant. Also, that in climates with more heating requirements an adequate level of adaptation could be achieved by improving energy efficiency of the building envelope; for climates with more cooling needs it could only be achieved with the addition of energy efficiency equipment and renewable energy. For the social housing sector, Roders [20] did a qualitative study of the likelihood of the adoption of five adaptation measures to the housing stock for housing associations in the Netherlands. Results showed that climate change is still not considered, but many housing associations saw an opportunity in receiving a selection of strategies and information on the most appropriate combination. In Brazil, future regional weather data is generally not available and aside from few studies, among which are Casagrande [21] and Alves, Duarte and Gonçalves [22], there is still limited research analysing building performance in response to climate change, especially for social housing. Therefore, the aim of this paper is to investigate the result of analysing the thermal and energy performance of projects developed for national Programs of Social Housing considering climate change; and to assess the impact on the operational phase of incorporating energy efficiency measures in the sector, and exploring methods of adaptation to climate change with focus on the thermal and energy performance of the envelope. The analysis was done using thermal and energy simulation of a project representative of the lower income sector. This research is part of a broader study found in Triana [23] that has as main goal to evaluate the incorporation of energy efficiency measures in Brazilian social housing, through an integrated life cycle approach considering climate change and aspects of sustainability with focus on the thermal and energy performance of the building. The first part of the current paper introduced the context of the study and covered the literature review on relevant topics for the research. The second part describes the method used and presents the evaluated measures for energy efficiency. The final parts are the results, discussion and conclusions of the study.

2. Method

The following was undertaken in order to do this study: a) preparation of future weather files for the selected cities; b) identification of parameters for thermal and energy simulation for the representative project considering two forms of operation: natural ventilation and with use of HVAC, and c) definition and evaluation of adaptation measures through indicators in the buildingís operational phase.

2.1. Future weather files

This study addressed climate change in terms of the variables that influence thermal and energy performance of the building. This research is aware of IPCCís suggestion that more climate models should be used for the evaluation of future weather to take uncertainties into account. However, since regional data was not available for this study, this research adopted the use of the CCWorldWeatherGen Tool version 1.8 to convert current Brazilian weather files to future weather files for use in the thermal and energy simulations. According to Robert and Kummert [24], the HadCM3 model that is considered in the CCWorldWeatherGen Tool is a model with mesh point with cells every 2.5° in latitude and 3.75° in longitude, the cell size being approximately 300 km x 300 km. The model gives monthly mean values for time horizons that represent average conditions of a period. Typically, the year 2020 represents the period from 2011 to 2040, the year 2050 the period from 2041 to 2070 and the year 2080 represents the period from 2071 to 2100.



Source: Malte Meinshausen in [13].

Fig. 1. CO_2eq concentrations for the different scenarios.

Source: Malte Meinshausen in [13].

Files from São Paulo and Salvador in TRY format were used, available in LABEEE [25]. The year corresponding to the files for the two cities is within the period from 1961 to 1990, in accordance with the recommendation of the tool. Therefore, the future weather files from both cities were obtained using the CCWorldWeatherGen Tool. The files were converted to EPW files following the methodology of the tool in Jentsch et al. [16] considering only the years 2020 and 2050. Since 2020 represents the period from 2011 to 2040, and the year 2050 the period from 2041 to 2070, it was assumed that the 50 years period of the expected building life was represented. The analysis was made of buildings in two Brazilian cities; São Paulo and Salvador. Both cities have a high housing deficit and they have different and extreme weather. Buildings in São Paulo (SouthEast region) has necessities for cooling and heating and those in Salvador (Northeast region) only for cooling throughout the year.

2.2. Base case of representative project

The representative project of the detached house typology for the lower income sector in social housing characterized by Triana, Lamberts and Sassi [10] was used as base case for this study. The house has a net area of 39,75 m^2. Fig. 2 shows the floor plan and the simulation model of the detached house.

The project was evaluated using the thermal and energy simulation software EnergyPlus v. 8.2. The EnergyPlus program, developed by the US Department of Energy, models the performance and energy consumption of multizone buildings based on the building design and climate data [26], as well as other parameters. The Energy Plus Program allows simulations of artificially conditioned and naturally ventilated buildings. Four thermal zones were created: living, bedroom 1, bedroom 2 and bathroom, all with a ceiling height of 2.5m. The attic was also modelled as a thermal zone. The next sections describe the parameters needed for the thermal and energy simulation.

2.2.1. Envelope components

Description and thermal properties of the envelopeís components for the base case are placed in Table 1.

2.2.2. Definition of internal loads for thermal and energy simulation

For the definition of internal loads in the two cities, five references were analysed. Three of them were national surveys: Information System of Appliances Possessions and Consumer Habits – SINPHA [27], National Survey by Household Sampling – PNAD [28] and 2010 Census [29]. Also, data from the Brazilian Energy Labelling [30] and the National Electric Energy Agency – ANEEL [31] was reviewed. There were significant differences between regions for some end-uses; however, it is believed that in future the most striking differences will diminish as increases in the family income will enable occupants to create more comfortable homes with air conditioning. Therefore, electric consumption for the base case was estimated to be 136.65 kWh/month (for lighting, hot water and appliances except air conditioning). This value is in accordance with national studies. Of this, 64 kWh/month was related to hot water consumption. Occupancy patterns were based on the Brazilian Energy Label, and PNADís data. Although acknowledging some differences between Northeast and Southeast regions, to allow comparisons four users were assumed in both cities. Fig. 3 shows the internal loads.

2.2.3. Parameters for thermal and energy simulation with HVAC and natural ventilation

Simulations were run with two operation modes based on the Brazilian Energy Labelling. The first with exclusive use of natural ventilation and the second with use of HVAC during certain hours of the day. Simulations with natural ventilation were done using the airflow network object in EnergyPlus defined as happening 24 h per day throughout the whole year. The ventilation control mode was established by a temperature with a setpoint of 20 °C. The simulation of HVAC was used to see the expected energy use of artificial conditioning, since there is a current increase in the sector. It was modelled using the Packaged Terminal Heat Pump available in EnergyPlus and established for all main rooms (bedrooms and living room/dining/kitchen), linked to a thermostat established for heating on 19.5 °C based on De Vecchi et al. [32]. For cooling it was based on Sorgato [33] varying with a timer, being 24 °C from 7:00am to 12:00pm and 25 °C after 12:00pm until 7:00am. The HVAC systemís use followed occupancy of main rooms. The COP for cooling and heating was 3,24 W/W considered level A in the Brazilian Energy Labelling. The simulations assumed natural ventilation when the HVAC was not in use. And to consider ground temperatures, very significant for this typology, the "ground domain slab" from EnergyPlus was used.

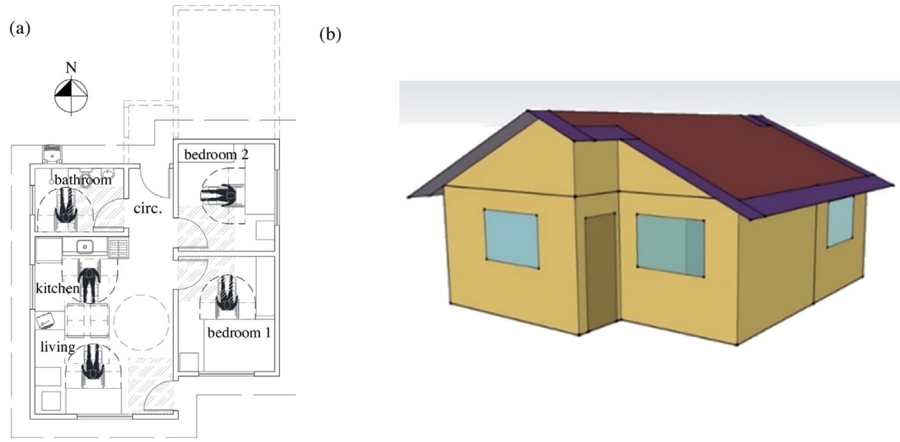


Fig. 2. Base case project – detached house: (a) floor plan and (b) simulation model.

Table 1
Components for the envelope of the base case in both cities.

Base Case	Description	U W/(m² K)	Thermal capacity kJ/(m² K)	(α)
External walls	13 cm (clay brick 9 × 14 × 19 cm with internal and external plastering).	2.43	132	0.6
Roof	2 pitches, red clay tile + roof void with PVC ceiling.	1.75	21.4	0.6
Floor	Ceramic tile 1 cm + 2 cm mortar + 5 cm concrete subfloor + 3 cm concrete ballast gravel			
Windows	Living and bedrooms: 1.50m²–2 Slide sashes horizontal, sill = 1.10 m (VF = 0.45; LF = 0.8); Kitchen: 1.20m² – 2 Slide sashes horizontal (VF = 0.45, LF = 0.80); Bathroom: 0.48 m² – framed glass louvres, sill = 1.50m, VF = 0.90; LF = 0.65; No external shutters; Glass: 4 mm transparent; Frames in aluminium.			
Doors	External doors: 2 of 0.80 × 2.10 m in metal; Internal doors: 0.80 × 2.10 m in wood.			

Note:VF = Ventilation or opening factor for windows; LF = Lighting factor for windows; α = solar absorptance.

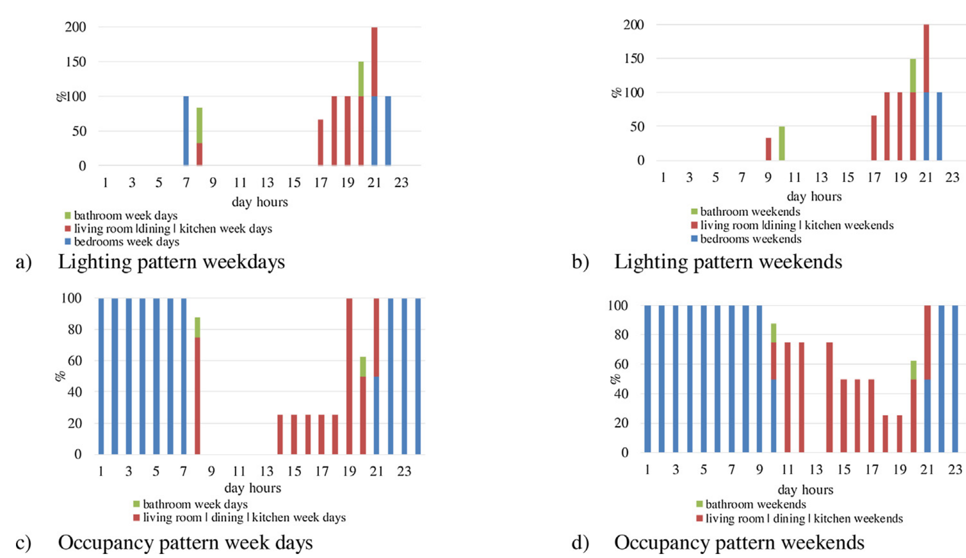


Fig. 3. Lighting and occupancy patterns for the project in both cities.

2.3. *Definition of adaptation measures*

As already stated, the literature review highlighted the importance of implementing measures to improve the thermal and energy performance of social housing. Thus, based on national references such as the Energy Labelling [30], Blue House Seal (Selo Casa Azul) [34] and a national project (SUSHI) [35], 33 possible adaptation measures were listed. Of these, the measures that showed more potential benefits related to user comfort with lower associated costs were analysed and selected for this study. Therefore, the adaptation measures considered were:

- **Improved thermal performance of the envelope's components:** with options for wall, roof and ceiling, considering components with greater thermal resistance, different solar absorptances and use of insulation;
- **Reduction of direct radiation on summer:** with windowís shading through the use of external shutters only for the bedrooms or for all main rooms;
- **Enhanced ventilation:** two measures were tested including an increase in the windowís ventilation factor for the main rooms, from 45% to 90% and increase in the windows size, first to meet the minimal requirements for the Brazilian Minimal Performance

Standard (NBR 15575) and later to exceed it by 20%. Both measures were also tested simultaneously.
- The effect of the building in contact with the ground was also tested.

Since the focus was on the envelope, appliances and lighting were assumed to be a fixed parameter in all scenarios. Measures were first evaluated through isolated analyses (one measure at a time), and in a second stage with combined measures, using for the parametric simulations the JePlus program version 1.5.1. The advantage of using this program for parametric simulations has been demonstrated by Zhang and Korolija [36].

2.3.1. Isolated analysis of the adaptation measures

Since houses are often build without considering their orientation, initially four orientations were tested (0°, 90°, 180°, 270°). The orientation with poorer performance in the analysed indicators (180°) was assumed for the base case and for all cases of the isolated analysis, considering that potential benefits of that orientation will be increased in others. Table 2 shows the identification and characteristic of the energy efficiency measures. Some measures for windows were different in São Paulo and Salvador, and are identified as SP (for São Paulo) or SAL (for Salvador). Totally 456 thermal and energy simulations were done at this stage: 216 for São Paulo and 240 for Salvador.

After the isolated analysis of the measures against the base case were done, some of the adaptation measures were analysed combined in parametric way.

2.3.2. Definition of combined adaptation measures

This simulation of combined adaptation measures considered only options that performed better on the first stage or that represented an average performance of a group. The combined measures that were tested are described as one of the measures adopted. All cases with combined adaptation measures at this stage assumed an orientation of 0° (Fig. 2) in the two cities. A total of 2004 cases were simulated for both cities, being 1722 for São Paulo and 282 for Salvador. Together with the first stage a grand total of 2460 simulations were done.

2.4. Indicators for evaluation: energy consumption and cooling and heating degree-hours

Indicators considered relevant for thermal and energy performance of the building in relation to climate change adaptation included: expected annual energy consumption with the use of HVAC and degree-hours for cooling and heating as an indicator related to thermal performance and therefore thermal comfort of the user (with heating degree-hours only in São Paulo). The results compared the base case and the cases with adaptation measures in the three climate scenarios (current, 2020 and 2050). Energy consumption considered the use of equipment, lighting and environmental conditioning obtained from the simulation with the use of HVAC, taking into account the total consumption in the living room/kitchen and bedrooms. Data was analysed annually in kWh/year and kWh/(m^2/year). The evaluation also considered the use of degree-hours, an indicator used in the Brazilian Energy Label for residential buildings. This indicator, although it shows the characteristics of thermal performance of the building, can be related to the userís thermal comfort for evaluating dwellings with use of natural ventilation and the operative temperature. Results for this indicator were obtained through simulations considering the house with the exclusive use of natural ventilation. The indicator was estimated annually based on the operative temperature in the main spaces. A ponderation considering the main roomís areas was done in order to have only one indicator per case. For the degree-hour a threshold temperature of 26° for cooling and 19.5 °C for heating was adopted. Results were shown for each indicator in the three climate periods. Fig. 4 shows a flow chart summarizing the steps of the methodology used.

3. Results and discussion

Fig. 5 shows the comparison of the current weather files and the two obtained through the CCWorldWeatherGen Tool: 2020 and 2050, for both cities including air temperature, relative humidity and global horizontal radiation. In São Paulo, comparing the current scenario with 2050, average temperatures showed a tendency to increase in the future scenario by 2 °C, overall, 3 °C in some months, especially between May and September. For Salvador, changes were more constant throughout the year with an average increase in temperatures around 2 °C. With the gradual increase in temperatures in future scenarios, there was a reduction in relative humidity. For São Paulo, the annual average showed a reduction of 2.4%, between the current and 2050 scenarios, while for Salvador was 1.3%. The annual average global horizontal radiation, showed an increase of 3.13 Wh/m^2 in São Paulo while Salvador showed a reduction of 5.24 Wh/m^2, comparing the current period with 2050.

Alves, Duarte and Gonçalves [22] used for their study regional data for São Paulo with the RCP 8.5 scenario. The RCP emission scenario considers different periods (near future, medium future and faraway future). The 2020 period from SRES corresponds to the near-future, the 2050 to the middle-future and the 2080 to the distant-future. The climate data used by the authors show around 1 °C difference in the annual mean temperature when comparing with the climate data used in this study, nevertheless showed similar performance in the mean monthly temperatures and the same heating tendency in the São Paulo future climate. This corroborates the use of the climate data in this study and gives confidence that the results represent a reliable tendency.

Results of the thermal and energy simulations are shown first for São Paulo in a more detail analysis and later for Salvador.

3.1. Analysis for energy efficiency adaptation measures for the project in São Paulo

In São Paulo, the base case showed an increase of cooling degree-hours and a reduction of heating degree-hours in the future climate. Considering the weighted average for the main rooms, the cooling degree-hours increased from 2447 in the current period to 7491 in the 2050 period. Also, comparing the same scenarios, the energy analysis of the base case showed an increase of 140% for expected cooling consumption, being predominant in all climate periods. Cooling increased from 19.12 kWh/(m^2/year) in the current climate to 45.92 kWh/(m^2/year) in the 2050 period.

Results for São Paulo for each adaptation measure analysed compared to the base case were as follows: the **solar absorptance of the wall**, had a greater influence in the 2050 period, especially for the indicator of cooling degree-hours. The case with a wall with solar absorptance 0.7 (darker colour) resulted in an increase in degree-hours of 1400 compared with the case of 0.2 solar absorptance (lighter colour) in the current climate. For 2050, that difference was 3200°-hours. Concerning **the walls construction materials,** walls with low thermal transmittance and medium/high thermal capacity, such as double brick wall, brick wall with insulation and concrete wall with insulation showed better performance for all indicators in the three climate periods. Walls with low thermal capacity and either with medium or low thermal transmittance like wooden walls had low performance for the cooling and heating degree-hour indicators. Wooden and concrete walls without insu-

Table 2
Energy efficiency adaptation measures evaluated with identification and characteristics.

Adaptation Measures		Description		
Reduce summer direct radiation	Shading	**Window_VF45_base case**: **(base case)** VF 0.45, without shading | **Window_VF45_shad_bedr: VF 0.45, shading on bedrooms | Window_VF45_shad_all: VF 0.45, shading on all rooms**		
		VF (ventilation factor)		
Enhanced ventilation	Changes in windows	**Window_VF90**: VF 0.90, without shading | **Window_VF45_higher_SP**: VF 0.45, without shading and 0.20 cm higher all windows | **Window_VF45_lowsill_ SAL**: VF 0.45, without shading and sill 0.30 cm lower for living/kitchen | **Window_VF90_higher_SP**: VF 0.90, without shading and 0.20 cm higher all windows | **Window_VO90_lowsill_SAL**: VF 0.90, without shading and sill 0.30 cm lower for living/kitchen | **Window_VF45_higher_SAL**: VF 0.45, without shading and 0.20 cm higher all windows | **Window_VF90_higher_SAL**: VF 0.90, without shading and 0.20 cm higher all windows | **Window_VF45_higher_lowsill_SAL**: VF 0.45, without shading, 0.20 cm higher all windows and sill 0.30 cm lower for living/kitchen | **Window_VF90_higher_lowsill_SAL**: VF 0.90, without shading, 0.20 cm higher all windows and sill 0.30 cm lower for living/kitchen.		
Improved thermal performance of the envelope	Solar absorptance of exterior walls −(α) or ABS	ABS 0.2 | ABS 0.3 | ABS 0.4 | ABS 0.5 | ABS 0.6 **(base case)** | ABS 0.7		
	Wall	**BRICK WALLS** (All with 2 cm internal and external plaster)	**U** W/(m^2 K)	**Thermal capacity** kJ/(m^2 K)
		Wall_base case: 9 × 14 × 19 cm, 6 holes brick (13 cm total) **(base case)**	2.43	132
		Wall_double brick: Double 6 holes brick of 9 × 14 × 19cm+ 3 cm air cavity (25 cm total)	1.24	174
		Wall_brick_15 cm: 11 × 19 × 19 cm, 8 holes brick (15 cm total)	2.24	133
		Wall_brick_18 cm: 14 × 19 × 19 cm, 9 holes brick (18 cm total)	1.84	145
		Wall_brick_ins: 9 × 14 × 19 cm, 6 holes brick + 2.5 cm rock wool (15.5 cm total)	0.99	135
		WOOD WALLS	**U**	**Tc**
		Wall_wood: double panel wood wall (2.2 cm) with 5 cm air cavity	1.60	30
		Wall_wood_insul: double panel wood wall (2.2 cm) with 5 cm wool rock	0.64	34
		CONCRETE WALLS	**U**	**Tc**
		Wall_conc: 10 cm concrete wall	4.40	230
		Wall_con_ins: 10 cm concrete wall + 2.5 cm rock wall+ 2 cm external plaster	1.24	281
	Roof	**CLAY TILE** (considering PVC ceiling)	**U**	**Thermal capacity**
		Roof_base case: clay tile no insulation **(base case)** (solar absorptance 0,6)	1.75	21.4
		Roof_clay_2.5ins_α0.6: clay tile with 2.5 cm rock wool (abs 0.6)	0.89	22.17
		Roof_clay_5ins_α0.6: clay tile with 5 cm rock wool (abs 0.6)	0.59	23.86
		Roof_clay_7ins_α0.6: clay tile with 7 cm rock wool (abs 0.6)	0.41	25.21
		Roof_clay_α0.5: clay tile no insulation (solar absorptance 0.5)	1.75	21.4
		Roof_clay_2.5ins_α0.5: clay tile with 2.5 cm rock wool (abs 0.5)	0.89	22.17
		Roof_clay_5ins_α0.5: clay tile with 5 cm rock wool (abs 0,5)	0.59	23.86
		Roof_clay_7ins_α0.5: clay tile with 7 cm rock wool (abs 0,5)	0.41	25.21
		METAL TILE (considering PVC ceiling)	**U**	**Thermal capacity**
		Roof_metal_α0.3: metallic tile no insulation (abs 0,3)	1.78	24.53
		Roof_metal_2,5ins_α0.3: metallic tile with 2.5 cm rock wool (abs 0.3)	0.90	26.22
		Roof_metal_5ins_α0.3: metallic tile with 5 cm rock wool (abs 0.3)	0.60	27.90
		Roof_metal_7ins_α0.3: metallic tile with 7 cm rock wool (abs 0.3)	0.42	29.25
	Ceiling	**Ceiling_PVC_base case**: 1 cm PVC **(base case)** | **Ceiling_wood**: 1 cm wood | **Ceiling_conc_EPS**: 12 cm concrete slab+ EPS		
	Ground Contact	**Ground_base case**: Building in contact with the ground **(base case)** | **Ground_without**: Building at 0.60 cm from the ground		

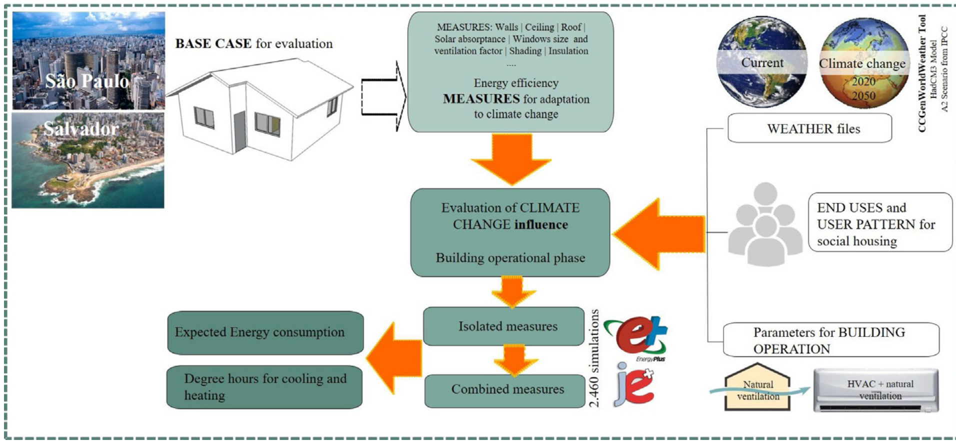


Fig. 4. Flow chart of the methodology.

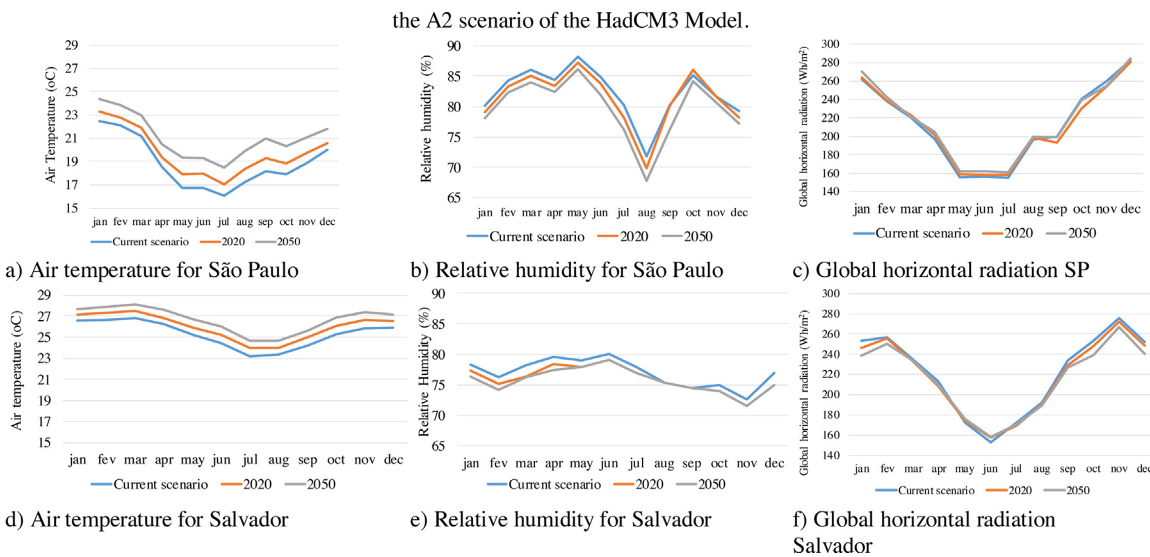


Fig. 5. Monthly average data for São Paulo and Salvador considering the current weather file, 2020 and 2050 previsions for the A2 scenario of the HadCM3 Model.

lation performed differently depending on the climate period and indicator. The wooden wall without insulation presented the worst performance in current and 2020 period for the cooling consumption indicator. By 2050 the worst performance for that indicator was observed for the concrete wall without insulation, followed by the base case. For heating consumption, the concrete wall without insulation, wooden wall without insulation and the base case, resulted in the highest consumption. Although the heating consumption was considered low and only relevant in the current climate. All **roof measures** improved the performance in relation to the base case, for the cooling degree-hour indicator. But, this was not the case for the heating degree-hour indicator. The cases that had a roof without insulation exhibited higher degree-hour for both cooling and heating. Overall, the roof with metal tile, solar absorptance 0.3 (light colour) and 7 cm of insulation had the best performance in the cooling degree-hour for the three periods, mainly due to the lower absorptance and the insulation layer. The cases with clay tile with lower solar absorptance and thicker insulation also achieved similar performance than the roofs with metal tiles. 5 cm or more insulation was observed to be more effective in roofs with medium solar absorptances. In terms of energy consumption, the performance of all cases was similar with natural ventilation, and roofs with insulation presenting better performance in the three climate periods. Roofs with higher insulation (7 cm) showed better performance, although the difference with lower thicknesses insulation (2.5 cm and 5 cm) was not significant for cases with HVAC, and more significant for cases with natural ventilation. Regarding the **ceilings**, for all indicators, the concrete slab with EPS ceiling exhibited slightly superior performance compared to other ceiling types, being more evident for the 2050 period; although the three ceilings showed similar behaviour, especially comparing the PVC and wood. All measures related to **enhanced ventilation and windows shading** showed improvements compared to the base case for the cooling indicators. Major differences were observed for the natural ventilation options. Shading in all rooms obtained the best performance in all indicators and three climate periods, followed by the measure of 90% ventilation factor and later for the measure of bigger windows with ventilation factor of 90%. However, the increase in windows size alone did not appear to be as effective as shading or increased in the ventilation. For all indicators, the case without **contact with the ground** showed lower performance in all climate periods.

All measures assessed at the first stage are shown in the same graph for performance comparison in the three climate periods for each indicator. Fig. 6 shows the results for cooling and heating degree-hour, both for the base case and cases with adaptation measures evaluated each at a time. The blue dot (bottom line) shows the performance in the current climate; the red dot in the 2020 period and the green dot, the 2050 period. The dotted line shows the band performance of the base case considering the three climate periods.

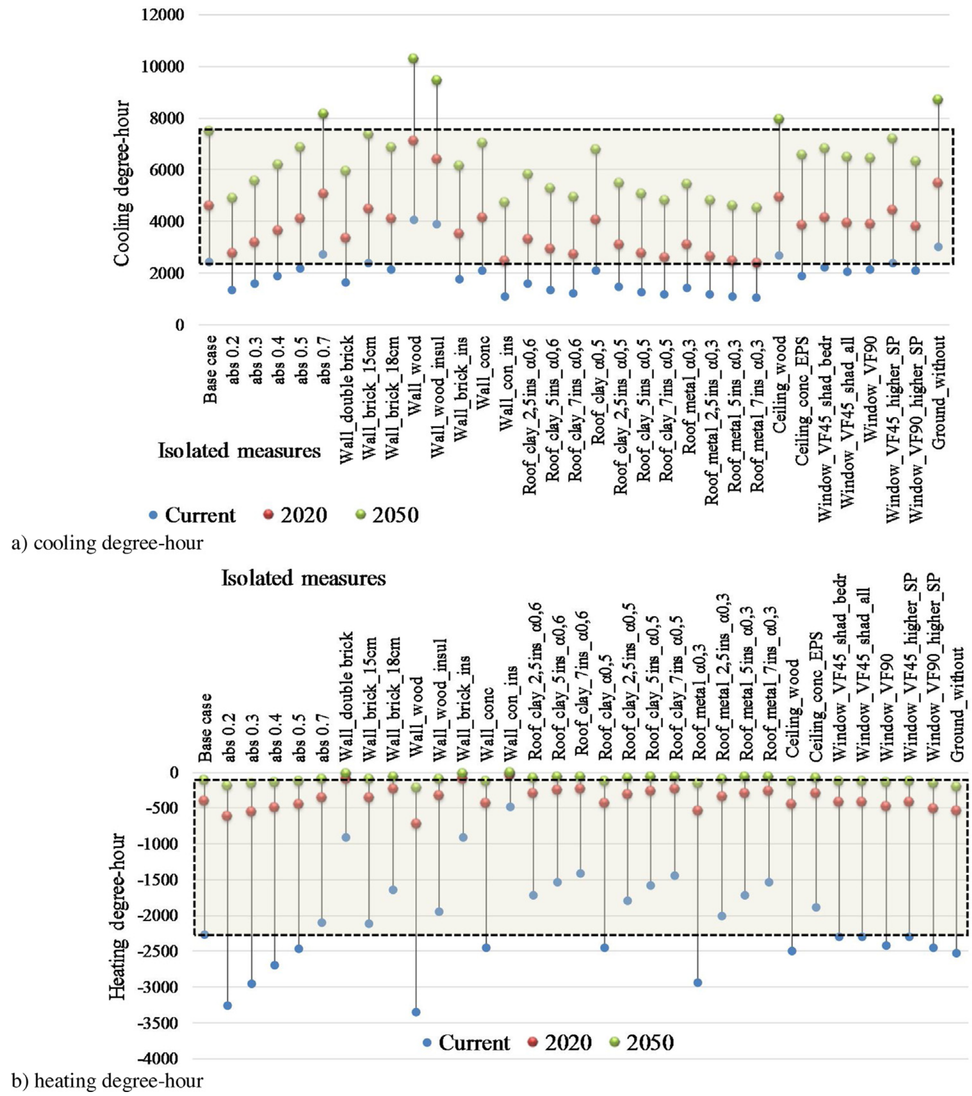


Fig. 6. Results for the indicators for natural ventilationís operation for the base case and cases with energy efficiency adaptation measures in São Paulo.

Considering all adaptation measures analysed in comparison to the base case and for the cooling degree-hour indicator, the highest values were measured in the cases with wood walls, and to a lesser degree in the building above the ground, and with greater solar absorptance for external walls and wood ceiling. While the lowest values, or better performance were to be measured in the cases related to changes in walls construction, roof construction and low solar absorptance for exterior walls. For the building in São Paulo, changes to the windows, although showed a reduction in the cooling degrees-hour, did not represent as significant a difference as other measures. Reductions in the cooling degree-hour comparing the base case with the most relevant adaptation measures for the current and 2050 period are as follows: Wall with solar absorptance 0.3 (current: 34.28% | 2050: 25.97%); double brick wall (32.82% | 20.64%); brick wall with insulation (27.59% | 17.79%); concrete wall with insulation (55.55% | 37.14%); clay roof with 5 cm insulation and solar absorptance 0.5 (48.35% | 32.50%); metal roof 7 cm insulation and solar absorptance 0.3 (57.87% | 39.88%); shading all rooms (15.34% | 13.62%) and bigger windows with ventilation factor of 0.90 (13.57% | 15.50%).

In relation to the heating degree-hour indicator, several measures increased the heating degree hours compared to the base case, especially low solar absorptance (lighter colour) in walls and roofs, the wooden walls, the concrete walls without insulation, and the windows with ventilation factor of 0.90. On the other hand, measures related to walls, especially, with higher thermal capacity (double brick wall) and with insulation (brick and concrete), showed a significant reduction for the heating degree-hour indicator.

Fig. 7 shows the energy consumption for heating and cooling together expressed in kWh/m^2/year due to the HVAC consumption. In relation to the expected use of HVAC for cooling and heating, measures to the roof including lower solar absorptance (light colour) and insulation stand out as displaying a good performance, as well as the measure of lower absorptance on the exterior walls. Also, some measures related to changes in walls presented good performance, as the double brick wall and the insulated walls (brick and concrete).

Reductions in the expected energy consumption of HVAC comparing the base case to some measures analysed considering the current climate and 2050 period are as follows: wall absorptance 0.3 (current: 21.86% | 2050: 20.98%); double brick wall (26.18% | 13.61%); insulated brick wall (23.94% | 12.87%); insulated concrete wall (40.82% | 21.74%); clay roof with 5 cm insulation and solar absorptance 0.5 (28.18% | 19.13%); metal roof 7 cm insulation and solar absorptance 0.3 (34.07% | 23.64%); shading all main rooms

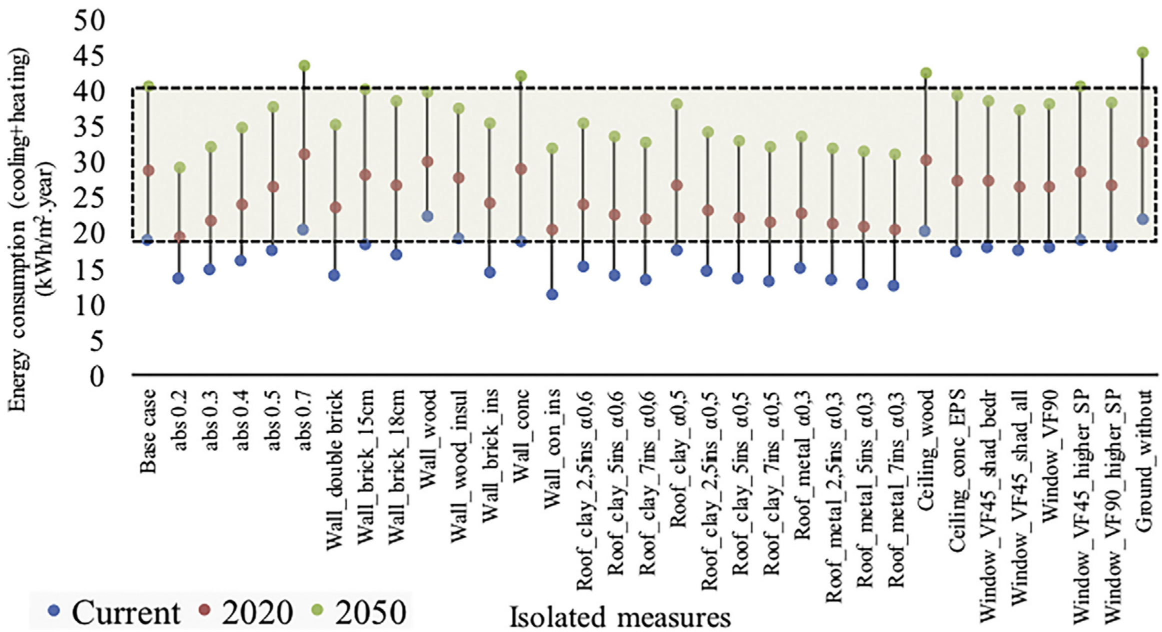


Fig. 7. Results per m^2 of the base case and adaptation measures for the house in São Paulo with the expected consumption of HVAC for cooling and heating in the three periods.

Table 3
Combined measures analysed in São Paulo in the parametric simulations for the three climates.

Aaptation Measures	Measures for São Paulo
Orientation	Azimuth 0° (assumed on all cases with combined measures)
External walls solar absorptance	ABS0,3 | ABS0.6
External walls type	Wall_double brick | Wall_brick_18 cm | Wall_wood_insul | Wall_con_ins
Roof type	Roof_clay_5ins_α0.5 | Roof_metal_5ins_α0.3
Ceiling type	Ceiling_PVC_base case | Ceiling_wood | Ceiling_conc_EPS
Windows shading	Window_VF45_shad_bedr (assumed for all cases with combined measures) | Window_VF45_shad_all VF (ventilation factor)
Ventilation factor for windows in main rooms	Window_VF45_base case | Window_VF90 | Window_VF45_higher_SP
Contact with the ground	Ground_base case (assumed for all cases)

(7.41% | 8.22%) and bigger windows with ventilation factor of 0.90 (4.67% | 5.82%).

After the analysis of the isolated measures, some measures were chosen for combined evaluation, based on those that presented better performance or representative performance of a group. Table 3 shows the measures chosen for São Paulo

The combination of measures can change the thermal properties of the building elements (e.g. the roof). Table 4 shows the thermal properties for the selected roofs with the combined ceilings.

Fig. 8 shows the results for the indicator of cooling degree-hour of the combined adaptation measures for the project in São Paulo, in the current and 2050 period. Results are organized in ascending order from the worst performance (base case) to the best performance. The base case is shown with a thicker line.

For the cooling degree-hour indicator, comparing the base case against the incorporation of combined adaptation measures, reductions of around 40% up to 90% were reached with little variation for all climate periods. However, it is emphasized that these results are considering user operating windows and external shading as defined in the Energy Label (i.e. ventilating when convenient). This is especially important for cases with higher insulation and higher thermal capacity, such as the cases with concrete wall with insulation. The cases that had the lowest performance with cooling degree-hour in all scenarios had in common wooden walls with insulation with either solar absorptance 0.3 and 0.6 and 18 cm brick wall with solar absorptance 0.6. In contrast, the cases that showed the best performance had in common walls that already showed a good performance in the individual measures analysis, these being double brick wall and concrete wall with insulation with either 0.3 solar absorptance (better performance) or 0.6 solar absorptance, and also 18 cm brick wall with 0.3 solar absorptance.

Fig. 9 shows the results for expected cooling consumption with combined adaptation measures for the current and 2050 period. For expected cooling consumption, reductions obtained for the combined adaptation measures showed a tendency of variability according to the climate period, being around 34% to 80% for the current climate and from 32% and 69% for the 2050 period. Reductions were greater in the current climate due to the higher temperatures observed in the future periods.

For cooling consumption, the best results in all scenarios had in common the same wall as in the previous evaluation.

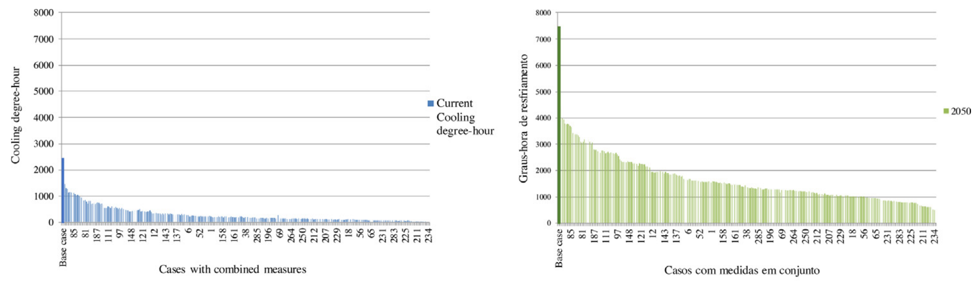
In 2050 period, 2/3 of the cases with the incorporation of combined measures would have the potential to maintain the same actual performance as the base case in the current climate based on the cooling degree-hours indicator, while for the cooling consumption this would apply to slightly less than half of the cases. The lower performance especially for the current and 2020 period is experienced in the option with double wood panel with insulation and solar absorptance 0.6. For the 2050 period the cases with 18 cm brick wall with solar absorptance 0.6 and clay tile with solar absorptance 0.6 had similar, and sometimes better performance than the cases with double wood panel insulation and solar absorptance 0.6.

3.2. Analysis for energy efficiency adaptation measures for the project in Salvador

For the project in Salvador, the measures analysed individually that represented a better performance than the base case in all indicators and the three climate periods were lower solar absorptance of the external walls; roof with lower solar absorptance and/or

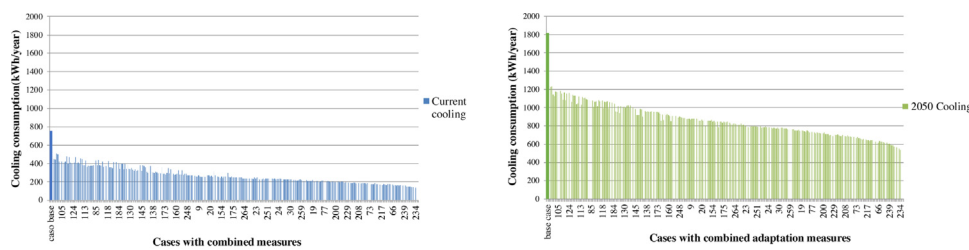
Table 4
Thermal properties of the selected combined roofs and ceilings.

	Description	**U** W/(m² K)	**Thermal capacity** kJ/(m² K)
Roof_clay_2.5ins_α0.5 + Ceiling_PVC_base case	Clay tile α0.5 + 5 cm rock wool + air cavity + PVC ceiling	0.59	23.86
Roof_clay_2.5ins_α0.5 + Ceiling_wood	Clay tile α0.5 + 5 cm rock wool + air cavity + wood ceiling	0.62	28
Roof_clay_2.5ins_α0.5 + Ceiling_conc_EPS	Clay tile α0.5 + 5 cm rock wool + air cavity + concrete slab with EPS ceiling	0.56	151
Roof_metal_5ins_α0.3+ Ceiling_PVC_base case	Metal tile α0.3 + 5 cm rock wool + air cavity + PVC ceiling	0.60	27.90
Roof_metal_5ins_α0.3+ Ceiling_wood	Metal tile α0.3 + 5 cm rock wool + air cavity + wood ceiling	0.63	32
Roof_metal_5ins_α0.3+ Ceiling_conc_EPS	Metal tile α0.3 + 5 cm rock wool + air cavity + concrete slab with EPS ceiling	0.57	155



a) Current climate b) 2050 period

Fig. 8. Results for current and 2050 period for the combined measures in São Paulo considering natural ventilation.



a) Current climate scenario b) 2050 climate scenario

Fig. 9. Results for expected cooling consumption for the base case and cases with combined measures in São Paulo.

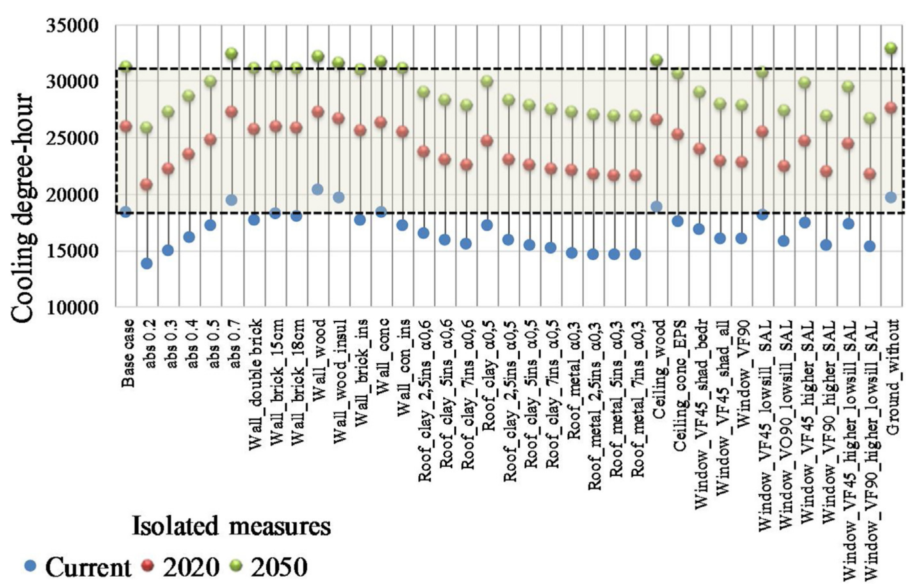


Fig. 10. Results of the isolated adaptation measures for the project in Salvador operating with natural ventilation.

insulation, and shading of windows in all main rooms. Wooden walls increased the cooling degrees-hours but decreased the indicator of expected cooling consumption. All measures proposed for the roof improved the performance in both indicators, particularly roofs with insulation and lower solar absorptance. In the current climate, thicker insulation results in a better performance mainly in the cooling degree-hours indicator, however, in the future climate, this improvement was reduced especially for the metal roof,

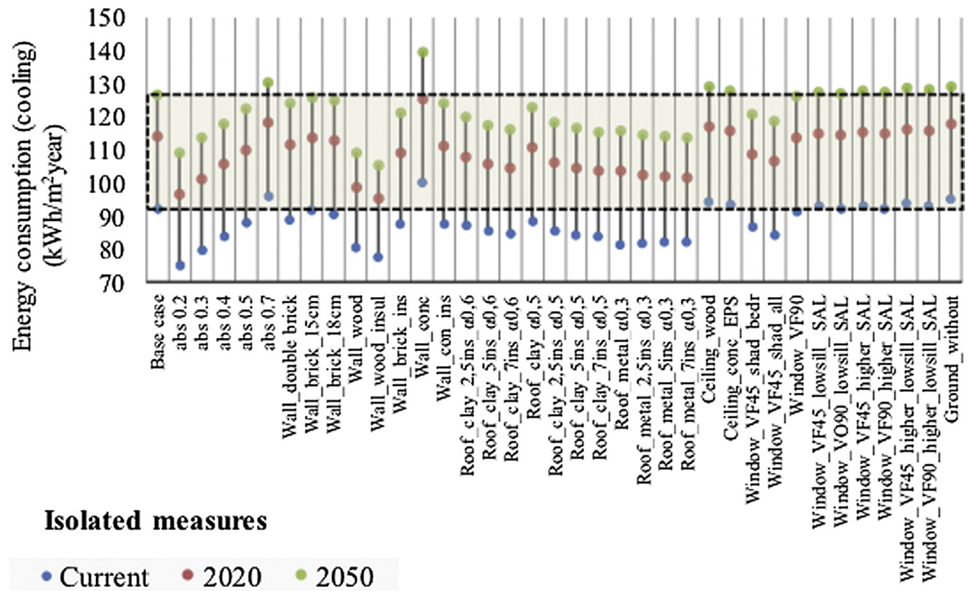


Fig. 11. Results of the isolated adaptation measures for the project in Salvador using HVAC – expected energy consumption.

Table 5
Combined measures analysed in the parametric simulations for the three climates in Salvador.

Adaptation Measures	Measures for Salvador
Orientation	Azimuth 0° (assumed on all cases with combined measures)
External walls absorptance	ABS0.3 | ABS0.6
External walls type	Wall_brick_15 cm | Wall_wood_insul
Roof type	Roof_clay_5ins_α0.5 | Roof_metal_5ins_α0.3
Ceiling type	Ceiling_PVC_base case | Ceiling_wood | Ceiling_conc_EPSFOR2
Windows shading	Window_VF45_shad_bedr (assumed for all cases with combined measures) | Window_VF45_shad_all
Ventilation factor for windows in main rooms	Window_VF45_base case | Window_VF90 | Window_VF45_higher_SAL and Window_VF45_lowsill_ SAL (assumed for all cases with combined measures)
Contact with the ground	Ground_base case (assumed for all cases)

which already benefited from lower solar absorptance. A very similar behaviour was observed in the ceilings proposed with respect to the base case, with little variation between them. For the measures proposed for windows, shading showed a significant improvement in both indicators as already stated. Other measures like the use of ventilation factor of 90%, also showed significant improvements for the degree-hour indicator. An enhancement in the ventilation factor combined with bigger windows showed an even better performance in the degree-hour indicator, especially in the future periods. However, bigger windows without enhanced ventilation factor did not present significant difference compared to the base case. Figs. 10 and 11 show all measures analysed each one at the time against the base case for the indicators: cooling degree-hour and expected energy consumption.

The measures that presented the best performance were chosen for the adaptation measures applied in combination. Table 5 shows the measures chosen for analysis in the city of Salvador.

Fig. 12 shows results of the combined measures for cooling degree-hour in the current and 2050 period.

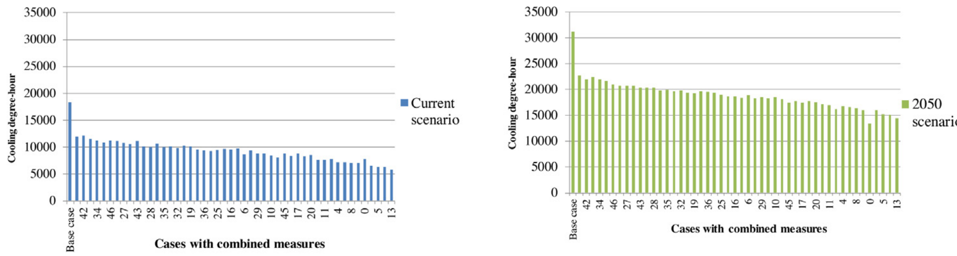
By combining adaptation measures in the current climate, reductions in cooling degree-hours were obtained ranging between 33% to 68%, compared to the base case. In the 2050 period reductions ranged between 27% to 53%. The three best cases for this indicator were masonry walls with solar absorptance (α) 0.3, shading to all main rooms; and windows with ventilation factor of 90%. Two of the cases had metal roof (solar absorptance 0.3) while one of them had clay roof (solar absorptance 0.5) both with 5 cm insulation. Fig. 13 shows the results for the expected cooling consumption.

For the combined measures and the indicator of expected cooling energy consumption, the maximum reductions observed were around 40% and the minimum around 12%, similar in all climate periods. For these indicators, the top three cases had shading in all rooms; wood ceiling and double wooden wall with (solar absorptance 0.3) and insulation. Two of the cases had a roof with metal tiles (solar absorptance 0.3 and 5 cm insulation) and two had a ventilation factor of 90%.

3.3. Discussion of the results

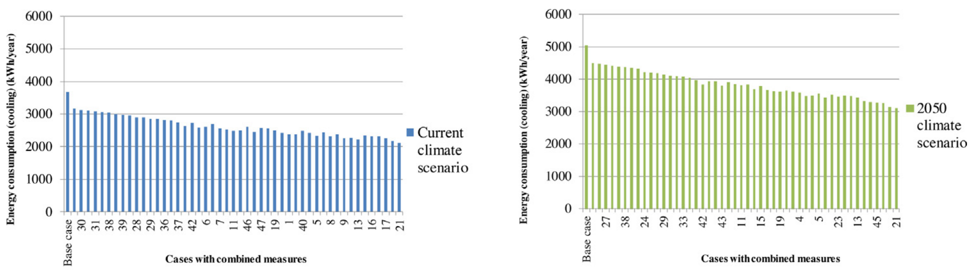
From the analysis of the results some considerations can be made. The base case presents low thermal and energy performance in the current climate, and is expecting to be worst for future climate in both cities.

For the dwelling in São Paulo, isolated measures that performed better in all indicators included changes in walls and roofs; in particular the use of walls with low thermal transmittance and medium/high thermal capacity; and roofs with insulation and lower solar absorptance. Lower solar absorptance of the wall was more effective in future periods due to future warmer climate. Reductions obtained using isolated measures were greater for the operation with natural ventilation and in the current climate. For the HVAC cases indicators reductions with isolated measures were a maximum of 40% for the current climate and 28% for the 2050 period. On the other hand, some isolated measures tested obtained inferior performance than the base case for São Paulo, such as building without contact with the ground. Also, the wooden walls showed lower performance than the base case with natural ventilation, especially considering cooling degree-hour, and had similar behaviour to the base case with HVAC. Isolated measures related to windows did not improve the performance of the dwelling in São Paulo as significantly as other measures, being more effective in the 2050 period, especially for the cooling degree-hour indicator.



a) Results for cooling degree-hour in the current climate b) Results for cooling degree-hour in the 2050 period

Fig. 12. Indicator in the operation of the building with natural ventilation for the current climate and 2050 period in Salvador.



a) Current climate b) 2050 period

Fig. 13. Indicator of expected cooling consumption for the project in Salvador.

The analysis of combined measures in São Paulo, confirmed that the wall and roof type with their associate thermal properties are of great relevance for the buildingís performance. The roofs analysed through the combined measures considered low thermal transmittance achieved by the insulation and the presence of a ceiling and low to medium solar absorptance. For São Paulo, in the combined measures analysis, the wall type showed a significant trend of the building performance. In general, cases with walls using absorptance 0.3 showed a better performance than those with absorptance 0.6, although, the absorptance of walls could be compensated by performance in other components. Enhanced ventilation in the windows was not very effective, but cross ventilation was more effective. Also for São Paulo, all measures applied in combination resulted in improvements in most indicators, except the heating indicators. For the indicator of expected cooling consumption, the reduction achieved with the combined adaptation measures in São Paulo showed variations according to the climate period between 32% and 69% for 2050. Greatest reductions were obtained in the current climate. Shading to windows was also important, especially for the bedrooms, since all the analysed cases for combined measures considered the use of external shutters in the bedrooms. However, the use of shutters in the living room/kitchen represents an adaptation that further improves the overall performance, but was not as significant as other measures.

For the dwelling in Salvador, measures analysed one at a time displayed smaller reductions in percentage than for São Paulo, because Salvadorís climate already has higher temperatures and showed comparatively less difference between the different climate periods than São Paulo. With the single measures analysis and for the cooling degree-hour indicator, the largest reductions were 25% for the current climate and 17% for the 2050 period. The adaptation measures that were most effective in all indicators were related to lower solar absorptance of the walls; roofs with insulation and lower solar absorptance; and shading to windows in all main rooms. Measures related to windows, both in increasing dimensions and the ventilation factor, were very effective for the operation with natural ventilation. On the other hand, the proposed changes for walls did not have a significant impact in Salvador, and the types of walls analysed showed, at times, different performance according to the indicator being evaluated. Wooden walls had lower performance than the base case for the cooling degree-hour indicator, especially in the current climate, being similar to the base case in the 2050 period. Yet, for the expected energy consumption for Salvador, wooden walls showed a performance significantly higher than the base case. On the other hand, measures such as concrete wall without insulation showed low performance, being the worst performance of the measures analysed with HVAC, which is consider a problem, since it is a current and recurrent practice.

Also for Salvador, considering the combination of adaptation measures, the ones that contributed the most for improving performance, were the lower solar absorptance of the walls and use of shading to all main rooms. The two types of roofs evaluated (clay and metal tile) did not present significant differences. Therefore, the use of the insulation was considered more important, since both specified roofs for combined measures had 5 cm insulation. The ceilings also did not show significant differences. For the evaluation of combined measures, the increase in windowís size was more relevant for improvement than the increase in ventilation factor, because all windows on that evaluation considered bigger windows than the base case. Cases with best performance were found in the same proportion with ventilation factor of 45% and 90%.

For both cities, the use of insulation on the roof appeared to be a very effective measure. However, for São Paulo, changing the thickness of the insulation in the roofs did not show significant difference in most of the indicators, being more relevant to the heating degree-hour indicator, but heating only appears relevant in the current climate. For Salvador, in roofs with lower solar absorptance (0.3), the insulationís thickness did not show differences between the evaluated indicators.

The use of external insulation on the walls for the project in São Paulo showed a tendency to improve the performance in the indicators evaluated in the three climates; however, for Salvador, external insulation on the walls did not result in significant improvements. Though, it is important to consider that the thermal and energy simulations were performed considering a type of user that shows an adequate control of the windowís opening and the shading

device. It may be important to analyse user behaviour in relation to other measures such as: insulation in walls, especially with higher thermal capacity, as in the case of the concrete wall, because if ventilation occurs on the hot period the heat can be storage into the walls and later release into the room, causing discomfort to the user.

The analysis of the isolated measures identified the most relevant measures for each city. The investigation of the combined measures showed that a good performance is possible to obtain with many combinations and highlighted a high potential to improve the base case performance in the 2050 period, compared to the current climate, for both cities. Results of this study demonstrated that the business as usual for the development programs for social housing should be reviewed taking into account climate change, and showed important opportunities for improvement of current and future social housing projects.

4. Conclusions

In this paper, energy efficiency measures for climate change adaptation were addressed considering the building envelope and addressing one building typology (detached house) that represents current practice in the lower income sector of Brazilian social housing. This research considered the base case and the incorporation of energy efficiency measures into the project, individually and combined, through thermal and energy simulation. The analysis was done for the cities of São Paulo and Salvador. The adaptation measures were evaluated according to annual indicators in the building operation including: expected energy consumption and cooling and heating degree-hours. The outcomes of the study showed that for dwellings with natural ventilation, the predominant form of operation in the country, the main problem will be to maintain adequate performance in the context of the warming predicted in future climate. The base case showed significant increase in indicators related to cooling in upcoming climate, in São Paulo and Salvador. On the other hand, in future climate periods a reduction in heating indicators was observed for São Paulo, making heating only relevant in the current climate.

Some differences in performance were observed relating to the climate period and the indicators evaluated. The results showed building performance trends for a future climate as established by the IPCC. Given the limitations of this study, which include the current uncertainty regarding future climates, the study being limited to one scenario and without an error analysis, it is suggested that the results of this research are be treated as a trend rather than as absolute values.

However, the results suggest some recommendations relating to current climate data that are reinforced if future climate data is considered. Taking this into consideration, the uncertainty of the future climate data does not affect the reliability of the main observations and recommendations of this study. For instance, in São Paulo, adaption measures evaluated in an isolated way, which proved to be very effective, are related to the improvement in the performance of walls and roof. Walls with low thermal transmittance and medium/high thermal capacity as double brick wall, brick wall with insulation and concrete wall with insulation had better performance in all indicators and all three climate periods. Also roofs with insulation and the measures related to windows showed similar performance in the three climate periods. Another important result is that the reductions achieved with the combined measures were observed in all climate periods being to be higher in the current climate for some indicators. Furthermore, for the evaluation of combined measures in São Paulo, changes in the wall resulted in a significant trend in the performance of the building in all climate periods with greater reductions for some type of walls experienced in naturally ventilated building and in the current climate. Some variations in the three climate periods in relation to performance improvements were measured in relation to wooden walls and concrete walls, whereby the lower solar absorptance of the wall enhanced the performance in the 2050 period.

A similar trend of improvements irrespective of climate period was measured for the project in Salvador. Measures analysed individually, such as, the lower solar absorptance of the external walls; lower solar absorptance and/or insulation of the roof, and shading of windows in all main rooms resulted in a better performance in relation to the base case in all indicators and all three climate periods. Furthermore, an enhancement in the ventilation factor combined with bigger windows showed an even better performance in the degree-hour indicator, in all three climate periods but especially in the future periods.

Considering that many measures where shown to affect performance in the same way in the different climate periods, the potential errors in the future climate data do not invalidate the results, which could confidently be used to advise state policy.

In conclusion, many measures improve current and future performance and therefore can benefit users now and in future. Thus, the importance of incorporating energy efficiency measures in projects in view of climate change is clear. Combined measures presented even better results for the improvement of thermal and energy performance than the use of individual measures, in current and future climate, and therefore represent the way forward and an approach to be recommended for implementation within the programs of social housing.

Also supporting these recommendations are the results from the analysis that show that some specifications that are currently being used in many social housing projects, such as concrete wall without insulation, higher solar absorption of the wall and some wooden walls without insulation (for the project in São Paulo), negatively affect the performance of the dwelling. These construction methods create uncomfortable buildings now that in future will be even more uncomfortable and therefore should be reviewed.

The methods currently adopted to design and specify social housing have been shown through this research to be problematic. The representative project of the detached house that currently showed a poor performance in the current climate would perform even worse in future. Traditionally projects are evaluated considering weather data from previous years that do not take into account the useful life of the building, estimated to be at least 50 years. There needs to be a change in the way projects are considered. Energy efficiency adaptation measures, applied in combination, have potential for a significant improvement in the indicators analysed in both current and future climate periods. Further research, investigating for example the design of the typology, could be beneficial in further optimising the energy efficiency design of the social housing units.

Some obstacles to the implementation of energy efficiency measures in social housing, such as higher cost, also demand further research into the building's whole life energy use in order to help prioritize the selection of building measures. Further studies might also simulate user behaviour other than that stipulated by the Brazilian Energy Labelling methodology. Other user behaviours may alter the results, particularly in the cases with external walls with insulation and, those that combine insulation with greater thermal mass, such as the case of the concrete wall, especially for São Paulo.

Finally, without incorporating energy efficiency measures in the projects that are being built for the social housing sector today, a trend of increased energy consumption associated with air conditioning can be expected. For Brazil, this would have a high impact on resource consumption. Thus, incorporating energy efficiency measures in social housing projects today is not only essential for creating comfortable homes for their users, but fundamental to

minimize the effects of climate change in the coming decades, and for reducing serious pressure on the energy infrastructure of the country.

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References

[1] CIBUNEP-IETC, Agenda 21 for sustainable construction in developing contries, CSIR Build. Constr.Technol. (2002) Available in: http://cibworld.xs4all.nl/dl/publications/Agenda21Book.pdf.
[2] D. Williams, et al., Climate change influence on building lifecycle greenhouse gas emissions: case study of a UK mixed-use development, Energy Build. 48 (2012) 112–126, maio.
[3] Fundação João PINHEIRO. Deficit habitacional no Brasil 2013: resultados preliminares nota técnica. Belo Horizonte: [s.n.]. Available at: http://www.fjp.mg.gov.br/index.php/docman/cei/deficit-habitacional/596-nota-tecnica-deficit-habitacional-2013normalizadarevisada/file. Belo Horizonte, 2015.
[4] BRAZIL; MINCIDADES. Plano Nacional de Habitação. Available in: http://www.cidades.gov.br/index.php/plano-nacional-de-habitacao.html. 2009.
[5] BRAZIL; MINCIDADES. Portaria N. 465 de 3 de outubro de 2011. 2011.
[6] S. Bodach, J. Hamhaber, Energy efficiency in social housing: opportunities and barriers from a case study in Brazil, Energy Policy 38 (12) (2010) 7898–7910, dez.
[7] D. Curcio, R. Da, A.C.S. Da Silva, Desempenho térmico de habitações de interesse social, em edifícios multifamiliares, produzidas pelo programa de arrendamento residencial—PAR, na cidade de Pelotas/RS, in: IN XII ENCAC—Encontro Nacional de Conforto no Ambiente Construído/VIII ELACAC, Proceedings. . ..Brasília, 2013.
[8] G.I. Linck, R.S. De Albernard, G. Grigoletti, C. De, Avaliação do conforto térmico de habitações de interesse social da cidade de Santa Maria, RS, a partir da opinião dos usuários, in: In XII ENCAC ? Encontro Nacional de Conforto no Ambiente Construído/VIII ELACAC—Encontro Latinoamericano de Conforto no Ambiente Construido, Proceedings. . . Brasilia, 2013.
[9] L.S.S. Almeida, Influência de Parâmetros Físicos e geométricos no Desempenho Termoenergético de Habitações Unifamiliares. Master's Thesis, Civil Engineering Department, Federal University of Santa Catarina, Florianópolis, 2014.
[10] M.A. Triana, R. Lamberts, P. Sassi, Characterisation of representative building typologies for social housing projects in Brazil and its energy performance, Energy Policy 87 (December) (2015) 524–541.
[11] UNEP; WMO; IPCC. Ipcc Special Report—Emissions Scenarios. 2000.
[12] IPCC. Climate Change 2014. Synthesis ReportClimate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Disponível em: http://ar5-syr.ipcc.ch/. Geneva: 2014.
[13] IPCC; Ypersele J. Van. IPCC Fifht Assessment Report (AR5) now underway. Update on Scenario Development:from SRES to RCPs. Disponível em: https://unfccc.int/files/methods_and_science/research_and_systematic_observation/application/pdf/ipcc_van_ypersele.pdf. Cancún, 2010.
[14] S. Belcher, J. Hacker, D. Powell, Constructing design weather data for future climates, Build. Serv. Eng. Res. Technol. 26 (January) (2005) 49–61.
[15] M.F. Jentsch, A.S. Bahaj, P.A.B. James, Climate change future proofing of buildings—generation and assessment of building simulation weather files, Energy Build. 40 (January (12)) (2008) 2148–2168.
[16] M.F. Jentsch, P.A.B. James, Leonidas Bourikas, A.S. Bahaj, Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates, Renew. Energ. 55 (July) (2013) 514–524.
[17] Z. Ren, Z. Chen, X. Wang, Climate change adaptation pathways for Australian residential buildings, Build. Environ. 46 (November (11)) (2011) 2398–2412.
[18] T. Van Hooff, B. Blocken, J.L.M. Hensen, H.J.P. Timmermans, On the predicted effectiveness of climate adaptation measures for residential buildings, Build. Environ. 82 (2014) 300–316, dez.
[19] R. Gupta, M. Gregg, Using UK climate change projections to adapt existing English homes for a warming climate, Build. Environ. 55 (2012) 20–42, set.
[20] M. Roders, A. Straub, Assessment of the likelihood of implementation strategies for climate change adaptation measures in Dutch social housing, Build. Environ. 83 (2014) 168–176.
[21] B.G. Casagrande, Cenários climáticos futuros: diagnóstico prospectivo do desempenho termoenergético. Dissertação de mestrado. Programa de pós-graduação em engenharia civil, Universidade Federal do Espírito Santo, Vitória, 2013.
[22] C.A. Alves, D.H.S. Duarte, F.L.T. Gonçalves, Resiliência das edificações às mudanças climáticas na região metropolitana de São Paulo. Parte 2: Estudo de caso—Desempenho térmico de edifícios residenciais de idosos, In XIII Encontro Nacional e IX Encontro Latino-americano de Conforto no Ambiente Construido. Proceedings (2015).
[23] M.A. Triana Montes, Abordagem integrada no ciclo de vida de habitação de interesse social considerando mudanças climáticas (Integrated approach in the social housing life cycle considering climate change). Doctoral thesis, Federal University of Santa Catarina, Florianópolis, SC, 2016, Civil Engineering Post-graduation Program. Available at: http://www.labeee.ufsc.br/node/705. Accessed 20 April 2016, 472 p.
[24] A. Robert, M. Kummert, Designing net-zero energy buildings for the future climate, not for the past, Build. Environ. 55 (2012) 150–158, set.
[25] LABEEE. Site institucional. Acesso em: 20 fev.2015.
[26] L. Wang, J. Gwilliam, P. Jones, Case study of zero energy house design in UK, Energy Build. 41 (November (11)) (2009) 1215–1222.
[27] BRAZIL; ELETROBRÁS; PROCEL. Avaliação do mercado de eficiência energética no Brasil: Pesquisa de posse de equipamentos e hábitos de uso—ano base 2005. 2007.
[28] IBGE - BRAZILIAN INSTITUTE OF GEOGRAPHY AND STATISTICS. Síntese Indicadores Sociais 2013. Pesquisa Nacional por Amostra de Domicílios. Available at: http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/indicadoresminimos/sinteseindicsociais2013/. 2013.
[29] BRAZIL; Brazilian Institute OF Geography And Statistics -IBGE. Resultados do Universo do Censo Demográfico 2010. Available in: //ftp.ibge.gov.br/Censos/Censo_Demografico_2010/Resultados_do_Universo/tabelas_pdf/tab6.pdf. 2010.
[30] BRAZIL. Regulamento Técnico da Qualidade para o Nível de Eficiência Energética Edificações Residenciais. Available in: http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001788.pdf. 2012.
[31] ANEEL. Institutional site. Available in:http://www.aneel.gov.br/aplicacoes/noticias/Output_Noticias.cfm?Identidade=4101&id_area=90. Accessed 15 May 2015.
[32] R. De Vecchi, et al., Application of the adaptive model proposed by ASHRAE 55 in the Brazilian climate context: raising some issues, in: 8th Windsor Conference. Proceedings, Windsor, 2014.
[33] M.J. Sorgato, Desempenho térmico de edificações residenciais unifamiliares ventiladas naturalmente. Master's Thesis. Civil Engineering Post-Graduation Program, Federal University of Santa Catarina-UFSC, 2009.
[34] CAIXA. Selo Casa Azul. Boas práticas para habitação mais sustentável. (Jhon, V. e Prado, R. T. A., Orgs.). São Paulo: Página & Letras, 2010.
[35] UNEP. Projeto Sustainable Social Housing Initiative - Sushi - Relatório 3. Avaliação das tecnologias existentes no mercado e soluções para melhorar a eficiência energética e o uso racional da água em habitação de interesse social no Brasil. Disponível em: http://www.cbcs.org.br/sushi/images/relatorios/Final_Brazil_reports_160511/3_Avaliacao_120511.pdf. 2010.
[36] Y. Zhang, I. Korolija, Performing complex parametric simulations with jEPlus, in: SET2010 9th. International Conference on Sustainable. Proceedings, Shanghai, 2010.